

Fishery Data Series No. 13-60

Stock assessment of Arctic grayling in the Upper Goodpaster River, 2012

by

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December 2013

Alaska Department of Fish and Game

Divisions of Sport Fish and Commercial Fisheries



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Weights and measures (metric)		General		Mathematics, statistics	
centimeter	cm	Alaska Administrative Code	AAC	all standard mathematical signs, symbols and abbreviations	
deciliter	dL	all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.	alternate hypothesis	H _A
gram	g	all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.	base of natural logarithm	<i>e</i>
hectare	ha			catch per unit effort	CPUE
kilogram	kg			coefficient of variation	CV
kilometer	km	at	@	common test statistics	(F, t, χ^2 , etc.)
liter	L			confidence interval	CI
meter	m			compass directions:	correlation coefficient
milliliter	mL	east	E	(multiple)	R
millimeter	mm	north	N	correlation coefficient (simple)	r
Weights and measures (English)		south	S	covariance	cov
cubic feet per second	ft ³ /s	west	W	degree (angular)	°
foot	ft	copyright	©	degrees of freedom	df
gallon	gal	corporate suffixes:		expected value	<i>E</i>
inch	in	Company	Co.	greater than	>
mile	mi	Corporation	Corp.	greater than or equal to	≥
nautical mile	nmi	Incorporated	Inc.	harvest per unit effort	HPUE
ounce	oz	Limited	Ltd.	less than	<
pound	lb	District of Columbia	D.C.	less than or equal to	≤
quart	qt	et alii (and others)	et al.	logarithm (natural)	ln
yard	yd	et cetera (and so forth)	etc.	logarithm (base 10)	log
Time and temperature		exempli gratia		logarithm (specify base)	log ₂ , etc.
day	d	(for example)	e.g.	minute (angular)	'
degrees Celsius	°C	Federal Information Code	FIC	not significant	NS
degrees Fahrenheit	°F	id est (that is)	i.e.	null hypothesis	H ₀
degrees kelvin	K	latitude or longitude	lat or long	percent	%
hour	h	monetary symbols		probability	P
minute	min	(U.S.)	\$, ¢	probability of a type I error	
second	s	months (tables and figures): first three letters	Jan,...,Dec	(rejection of the null hypothesis when true)	α
Physics and chemistry		registered trademark	®	probability of a type II error	
all atomic symbols		trademark	™	(acceptance of the null hypothesis when false)	β
alternating current	AC	United States		second (angular)	"
ampere	A	(adjective)	U.S.	standard deviation	SD
calorie	cal	United States of America (noun)	USA	standard error	SE
direct current	DC	U.S.C.	United States Code	variance	
hertz	Hz			population sample	Var var
horsepower	hp				
hydrogen ion activity (negative log of)	pH				
parts per million	ppm	U.S. state	use two-letter abbreviations		
parts per thousand	ppt, ‰		(e.g., AK, WA)		
volts	V				
watts	W				

FISHERY DATA REPORT NO. 13-60

**STOCK ASSESSMENT OF ARCTIC GRAYLING IN THE UPPER
GOODPASTER RIVER, 2012**

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December 2013

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ABSTRACT

The abundance and length composition of Arctic grayling *Thymallus arcticus* in a 75 km study area (sampling Areas A, B, and C) of the Upper Goodpaster River (GPR) was estimated as part of a monitoring program relative to the Pogo Gold mine located approximately 109 km upstream from the river's mouth. The last stock assessment in this area occurred during 2003 and 2004 prior to mine construction, when a 44-km portion (Areas B and C located above and below the mine) of this reach was assessed. The inclusion of Area A (upstream of the previous assessment area) in 2012 permitted additional observations about the density and composition of Arctic grayling residing within the upper-most reaches of the GPR. A two-event mark-recapture experiment was conducted during July and early August of 2012. Hook-and-line gear was used exclusively to capture fish with the exception that electrofishing boats were used during the first event in the lower 28 km when water was high. Within the 75-km study area, a total of 1,800 Arctic grayling ≥ 300 mm FL were captured ($n_1=815$, $n_2=985$, $m_2=146$). Estimated abundance of Arctic grayling ≥ 300 mm FL was 5,467 (SE = 415) and estimated 75% of the population was 310-379 mm FL. Estimated abundance in Area A was 2,191 (SE=281), in Area B was 1,230 (SE=240), and in Area C was 2,202 (SE=236). Compared to estimates from 2003 and 2004, the point estimates for Area C, and Area B & C combined, were significantly greater in 2012 ($\alpha=0.05$). The point estimate for Area B was greater in 2012 but not significantly so. These results indicated that there was no evidence that development in the Upper Goodpaster River valley has had detrimental effects on the Arctic grayling population as measured by abundance and size composition. In fact, the density of Arctic grayling ≥ 300 mm FL in the Upper Goodpaster River (75 fish/km) was greater than has been observed in adjacent drainages such as the Upper Chena (31 fish/km) and Upper Chatanika rivers (36 fish/km).

Key words: Arctic grayling, *Thymallus arcticus*, abundance, length composition, hook-and-line, mark-recapture, Goodpaster River, Alaska

INTRODUCTION

Arctic grayling *Thymallus arcticus* are an important recreational species in clear-water rivers of Interior Alaska and are a top level aquatic predator making them a good indicator of river ecosystem health. Within the upper reaches of the Goodpaster River (GPR), a population of Arctic grayling has long existed virtually undisturbed. Based on previous studies, densities of Arctic grayling upstream of Central Creek are thought to be relatively low, about 50–60 fish ≥ 300 mm FL per km (Parker 2006; Parker et al. 2007; Tack 1974; Figure 1). Little is known about the seasonal habitats of these fish, but some individuals, residing there during summer, overwinter and spawn in the upper river while others utilize the lower river (Grysky *In prep*). In addition, some Arctic grayling tagged in the Upper GPR have been recaptured in the Delta Clearwater River one or more years later (Grysky *In prep*; Wuttig and Grysky 2010).

Within the Upper GPR watershed (Figure 1), successful gold exploration occurred during the 1990s and plans to construct a mine were developed. Prior to construction, Teck-Cominco (the original owner) and the Alaska Department of Fish and Game (ADF&G) agreed to proactively fund and collect baseline data on Arctic grayling for use in future monitoring of population abundance and ecosystem health. ADF&G has estimated abundance of the spring spawning population of Arctic grayling during 1997–2002 in the lower river (i.e., downstream of the South Fork) and the summer population adjacent to Pogo mine during 2003 and 2004. When abundance of Arctic grayling adjacent to the Pogo mine site was estimated, the project was designed to have estimates in two stretches of the river (one above and one below the mine, i.e., Glacier Creek to Liese Creek and Liese Creek to Barbara Creek) that could be easily replicated after the mine was constructed in 2006. As nearly six years have elapsed since mine operation, ADF&G and the Sumitomo Metal Mining Co., Ltd, (the current mine owner) agreed an estimate of Arctic grayling abundance in the Upper Goodpaster River was needed to evaluate current population status. The goal of this project was to examine for changes in estimated abundance and size composition of Arctic grayling adjacent to Pogo mine, last assessed in 2003 and 2004.

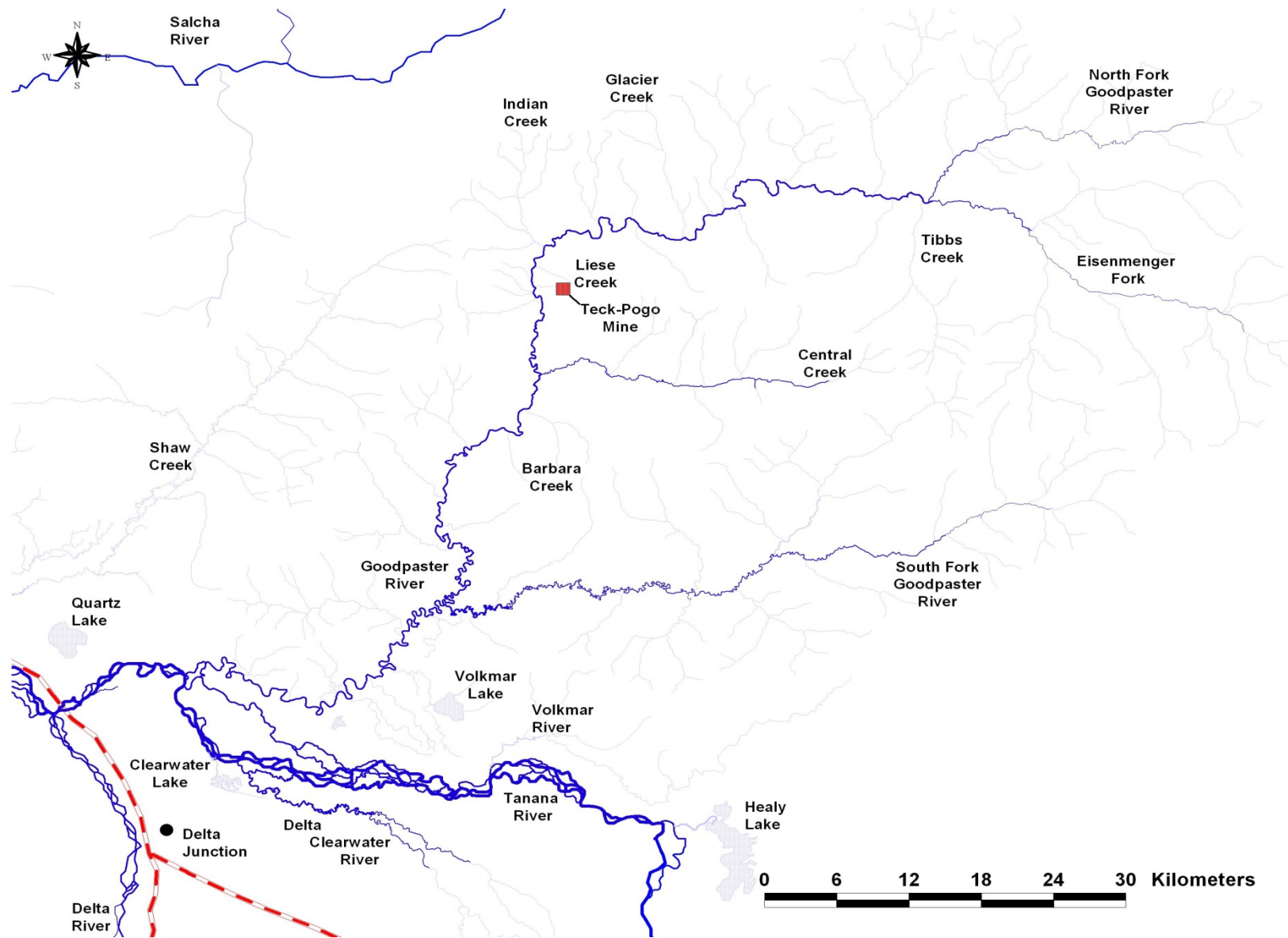


Figure 1.—The Goodpaster River drainage.

In addition, abundance and length composition were examined upstream in a 31-river km reach between Tibbs Creek and Glacier Creek to acquire additional observations about the density and composition of Arctic grayling residing within the upper-most reaches of the GPR.

OBJECTIVES

The research objectives for this project relate to 4 geographic strata within the Upper Goodpastor River:

- Area A: The upper most section between Tibbs and Glacier creeks (31 km).
- Area B: The middle section between Glacier and Liese Creek (2x km).
- Area C: The lower most section between Liese and Barbara creeks (2x km).
- Areas A, B, and C combined: Tibbs Creek to Barbara Creek (75 km).

The objectives for this study were to:

1. estimate the abundance of Arctic grayling ≥ 270 , ≥ 300 ; and ≥ 330 mm FL in July 2012 for each geographic strata such that the estimates are within 25% of the true abundance 95% of the time;
2. estimate the length composition (in 10 mm intervals) of the Arctic grayling ≥ 270 mm in July for each geographic strata such that the estimates are within ten percentage points of the true value 95% of the time; and
3. for Areas B and C, test the hypothesis that the 2012 estimates of abundance of Arctic grayling ≥ 300 mm FL are not less than the 2003 and 2004 estimates, using $\alpha = 0.05$.

The precision criterion for Objective 1 is a minimum regional standard regardless of population size, and typically provides sufficient power for the hypothesis test in Objective 3. The size categories identified in the objectives (270, 300, and 330 mm FL) are commonly used standards in Arctic grayling stock assessments or management objectives used by ADF&G, and were comparable to previous estimates in the study area. Objective 2 provided estimates of length composition within the study area. Although the length at which Arctic grayling recruit to the gear can range between 200 and 270 mm, only fish ≥ 240 mm FL were tagged because smaller fish were rarely captured in previous studies.

METHODS

STUDY AREA

The mainstem GPR is 211 km long and has a drainage area of 3,890 km² (Figure 1). The river is a rapid run-off stream that ranges from clear to slightly tannin stained, and it becomes turbid during periods of heavy run-off (Tack 1980). Upstream of Pogo Mine (river kilometer 109), the river has a drainage area of 1,753 km², and had a mean summer stream flow of 17.0 m³/s and a mean winter flow of 1.7 m³/s between 1997 and 2002. The GPR is accessible by river boat or airplane during the summer. The river can be reached via the Tanana River from boat launches at Big Delta (13.5 river km downstream of GPR mouth) and at Clearwater Lake (12 river km upstream from the GPR mouth). Riverboat navigation is consistently possible in the lower 101.4 km of the river (up to Central Creek) and the lower 16.1 km of the South Fork GPR.

Private landing strips are at Central Creek (river-km 101.4), at Pogo Creek (river-km 109), and at Tibbs Creek (river-km 161). As of 2002, there were reportedly 66 recreational cabins on the river, and all but eight were between river-km 4.8 and 48.3 (Parker 2003). There are several trapping cabins and one recreational cabin upstream of Central Creek.

The study area was located between the mouths of Tibbs and Barbara creeks, a distance of 75 km (Figure 2). The study area was divided into 16 sections averaging 4.6 km each (range 2.8–5.7; Table 1), and each section was bounded by pronounced geographic features such as Glacier, Liese, and Barbara creeks when possible.

EXPERIMENTAL AND SAMPLING DESIGN

This study was designed to estimate abundances and length compositions of Arctic grayling within three sections of a 75 km study area of the Upper Goodpaster River (Figure 2) during July 2012 using two-event Petersen mark-recapture techniques for a closed population (Seber 1982). The study was designed to satisfy the following assumptions:

1. the population was closed (Arctic grayling did not enter the population, via growth or immigration, or leave the population, via death or emigration, during the experiment);
2. all Arctic grayling had a similar probability of capture in the first event or in the second event, or marked and unmarked Arctic grayling mixed completely between events;
3. marking of Arctic grayling did not affect the probability of capture in the second event;
4. marked Arctic grayling were identifiable during the second event; and
5. all marked Arctic grayling were reported when recovered in the second event.

The sampling design and data collected allowed the validity of the five assumptions to be ensured or tested. The specific form of the estimator was determined from the experimental design and the results of diagnostic tests performed to evaluate if the assumptions were met (Appendices A1, A2, and A3).

The 75 km study area was divided into 3 areas having 5 or 6 sections each (Figure 2; Table 1). This division served to guide sampling and provided a minimum geographic scale at which to conduct diagnostic tests. The first event occurred during July 8–19, and the second during July 17–August 3. The project was designed to use hook-and-line gear to capture Arctic grayling; however, due to high water from abundant precipitation during early July, the lower sample area (sections 10–16) were sampled with an electrofishing boat during the marking event. During each event, the upper boundary of the study area was reached by helicopter, after which an inflatable canoe or raft was used to float and wade through each section (1–6). Power boats launched from Pogo mine were used to access all other sections (7–16).

The relatively short duration (7–15 days) and timing (summer) of the experiment minimized or eliminated bias associated with movements into or out of the study area. The short hiatus should have minimized potential bias due to growth recruitment and mortality, allowed for localized mixing of marked and unmarked fish to eliminate pockets of fish isolated from the sampling gear, and let marked fish adequately recover from the effects of handling between events. Studies have demonstrated that movements of Arctic grayling tend to be at a much smaller scale during the midsummer feeding period (generally defined as mid-June to August), as compared to post summer and post winter migrations associated with spring spawning and

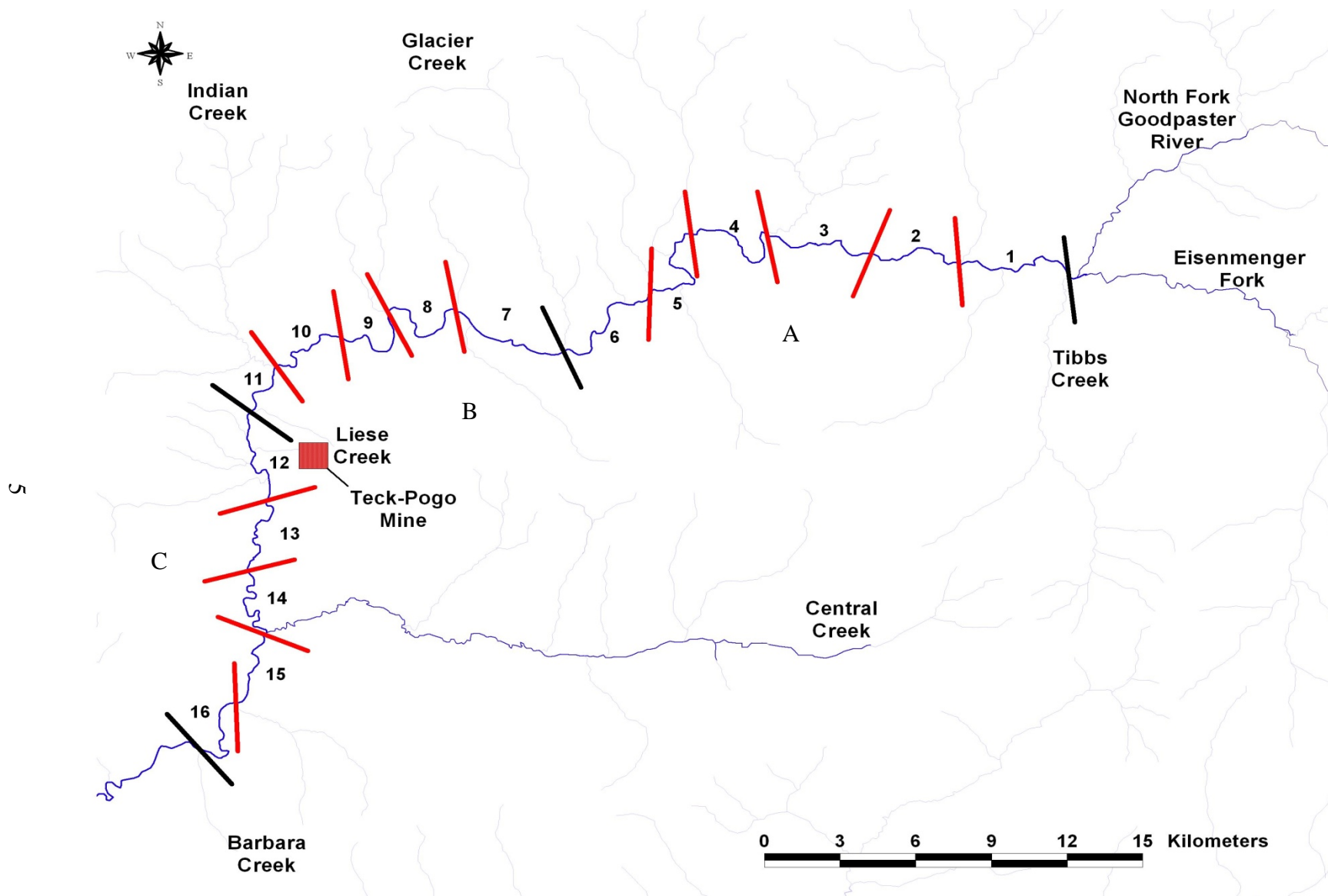


Figure 2.—Goodpastor River study area and sample Areas (A–C) and sections (1–16).

Table 1.—Sample Areas, sections, and distance (km) of each section.

Area	Section	Distance (km)
A	1	5.7
A	2	4.4
A	3	5.2
A	4	4.9
A	5	5.3
A	6	5.6
B	7	5.3
B	8	4.5
B	9	4.1
B	10	3.9
B	11	2.8
C	12	4.7
C	13	4.3
C	14	5.5
C	15	4.4
C	16	4.4

overwintering (Ridder 1998a-b; Gryska 2006). In addition, the movements of recaptured individuals were analyzed to evaluate the appropriateness of the assumption of closure.

When angling, a 2- or 3-person crew progressed downstream while attempting to catch fish, and sampled up to a section a day (variation due to logistical constraints, hydrologic conditions, and densities of Arctic grayling). All waters were angled in an effort to subject all fish to capture, and the daily effort was adjusted such that areas of high fish densities were fished for longer periods than low density areas to subject fish to more similar capture probabilities. The terminal gear consisted of a combination of flies (dry and wet) and rubber-bodied jigs. The degree to which each gear was used was left to each angler's discretion. Typically, jigs were used most often. At each angling location, captured Arctic grayling were temporarily held 1–10 minutes in a five-gallon bucket until data were collected. Afterwards they were generally released at or within 25 m of their capture locations, and in no cases were fish displaced by more than 100 m from a distinct habitat feature such as a pool.

For electrofishing, two boats were equipped with electrofishing gear as described by Gryska (2011a). In an attempt to distribute effort uniformly, the sampling area was fished in a downstream progression and boats operated in tandem on opposite sides of the river. If multiple channels were encountered, either one or two boats, depending on the size of the channel, sampled all channels that were navigable. Electrofishing boats were operated for up to 20-min

intervals, defined as a run, and each section required 1 to 3 runs to complete sampling. Captured Arctic grayling were held in an aerated tub until they were sampled and returned to the river approximately 500 m upstream from the end of a run.

Sample size objectives for estimating abundance were established using methods in Robson and Regier (1964) and for length composition using the criteria developed by Thompson (1987) for multinomial proportions.

DATA COLLECTION

All fish were measured for length (mm FL) and carefully examined for marks. In the first event, all fish ≥ 240 mm FL were tagged with an individually numbered FloyTM FD-94 internal anchor tag (green color, white print, numbered between 1–150; 201–363; 501–775; 802–979; 1,001–1,100; 1,201–1,300; 1,401–1,500; and 1,901–1,904) placed at the insertion of the dorsal fin so that the tag locked between the posterior interneural rays and received an upper caudal finclip to identify tag loss. To eliminate duplicate sampling in the second event, all fish received a lower caudal finclip. All fish in both events were carefully inspected for attendant FloyTM tags and finclips and had their capture/release locations recorded using a GPS (latitude and longitude coordinate as decimal degrees, NAD27 Alaska datum). Fish captured in the first event that exhibited signs of injury, excessive stress, or imminent death were not marked and were censored from the experiment.

DATA ANALYSIS

Abundance Estimate

When capturing fish in a river whether using angling or electrofishing equipment, it is inherently difficult to approximate the taking of a simple random sample (i.e., a random sample without replacement). Samples from the GPR were taken systematically in the sense of progressively moving downstream and sampling uniformly as described above so that, to the extent possible, fish were captured in proportion to their abundance throughout the study area. Under these circumstances the Bailey-modified Petersen estimator (Appendix A1; Bailey 1951, 1952) is preferred over the Chapman-modified Petersen estimator (Chapman 1951) for estimating abundance.

Relative to Assumption 1, closure was not tested directly but inferred from examination of the movement between capture locations of recaptured Arctic grayling within the study area. The data were examined for evidence of movement away from or towards the boundaries of the study area to provide evidence of significant immigration and emigration.

Violations of Assumption 2 relative to size were evaluated using Kolmogorov-Smirnov (K-S) two-sample tests with a significance level of $\alpha = 0.05$. There were four possible outcomes of these tests relative to evaluating size selective sampling (either one of the two samples, both, or neither of the samples had size selectivity) and two possible actions for abundance estimation (length stratify or not). The tests and possible actions for data analysis are outlined in Appendix A2. If stratification by size was required, capture probabilities by location were examined for each length stratum.

The tests for consistency of the Petersen estimator (Seber 1982; Appendix A3) were used to determine if, for each identified length stratum, stratification by location was required due to spatiotemporal effects and to determine the appropriate abundance estimator: the pooled Bailey-

modified Petersen estimator, the completely stratified Bailey-modified Petersen estimator, or a partially stratified estimator (Darroch 1961). Documentation of release location by section for each fish permitted the examination of multiple geographic stratification schemes for purposes of assumption testing, and testing was performed at the scale of sections (overall), sections within an area, and by area which corresponded to the previous study's groupings (Parker 2006; Parker et al. 2007). This grouping strategy also provided a sufficient number of recaptures for diagnostic testing to ensure negligible statistical bias in \hat{N} (Seber 1982) and accommodated localized movements (i.e., within a 1-km radius) of Arctic grayling.

Hypothesis Test

Z score tests were performed to test the null hypotheses that the 2012 population abundance estimates in two Areas (B and C) were no less than those abundance estimates for 2003 and 2004. For each test, a p-value was calculated to assess the likelihood of obtaining the observed z score assuming the null hypothesis was true. A p-value < 0.05 would reject the null hypothesis.

Length Composition

Length composition of the population was estimated in 10-mm length categories using the procedures outlined in Appendix A4.

RESULTS

Movement

When angling, fish were released relatively close to their capture location (within about 25 m), and movement was defined as a fish that was recaptured >0.5 km from its release location. Using this definition of movement, 47 of the 63 (75%) recaptured Arctic grayling did not move. The average distance moved by recaptured Arctic grayling was downstream 0.41 km, with a range of 10.4 km downstream and 3.9 km upstream. When electrofishing during the first event, some captured Arctic grayling were transported up to 1.5 km downstream from their original capture site while completing an electrofishing run. Using a definition of movement being >1 km, 67% (64 of 96) recaptured Arctic grayling did not move, and of those moving >1.0 km, 28 of 31 recaptured Arctic grayling moved upstream. The average distance traversed by recaptured Arctic grayling that had been marked while electrofishing was upstream 0.54 km, with a range of 6.4 km downstream to 6.9 km upstream. The overall average distance moved by recaptured fish was 0.16 km, and 71% of fish moved ≤ 1 km (Figure 3). The lack of any relatively large or unidirectional movements within the 75 km study area indicated that immigration or emigration were likely insignificant during the experiment.

Abundance Estimate

In the entire study area (75 km), 2,254 Arctic grayling ≥ 240 mm FL were captured ($n_1 = 1,026$, $n_2 = 1,228$, $m_2 = 159$). The smallest recaptured fish was 254 mm FL, but only 14 Arctic grayling 240–300 mm FL were recaptured of which all but one were captured in the lower most Area (Area C, sections 12–16). Therefore, abundance was independently estimated for 10 groups (i.e. populations) of Arctic grayling: fish ≥ 240 and ≥ 270 mm FL in Area C, and fish ≥ 300 and ≥ 330 mm FL in Areas A, B, C, and all Areas combined. Among the 10 groups (by size and area) on which K-S tests were performed, it was determined that each group was either Case I or II (Table 2), which indicated that there was either no size selective sampling during both events

(Case I) or that size selective sampling occurred during the second event (Case II). The entire data set was used without length stratification to estimate abundance, and, for Case I groups, data from both events were pooled for composition estimates. For Case II groups, data from the first event only were used for composition estimates. Among all size and Area groups, one or more consistency tests failed to be rejected (Tables 3 and 4). Therefore, there was no need to geographically stratify, and the Bailey-modified Petersen estimator was used to calculate abundances (Table 5). A substantial proportion (73%–80%) of the estimated population of Arctic grayling ≥ 300 mm FL was 310 to 379 mm FL (Tables 6–9). Relative to objective 3, there is strong evidence that the abundance estimates of Arctic grayling in 2012 for Area C and for Area B and C combined were greater than the estimates during 2003 and 2004 (Table 10). For Area B, there is no evidence that the abundance estimates were greater than those in 2003 and 2004 (Table 10).

DISCUSSION

Abundance of Arctic grayling was estimated throughout the study area for fish ≥ 300 mm FL, while estimates of small fish (≥ 240 and ≥ 270 mm FL) were attained only in Area C. The project was designed to obtain estimates of abundance and length composition of Arctic grayling adjacent to the Pogo mine site (Areas B and C) that were directly comparable to estimates determined prior to construction of the mine. Point estimates during 2012 in Areas B, C, and B&C combined were greater than that observed during 2003 and 2004, but only two of the 2012 estimates had 95% CI that did not overlap with CI of previous estimates (Area C, 2003; and Area B&C, 2004). Testing of the hypothesis indicated that the 2012 estimates were significantly greater ($\alpha=0.05$) than 2003 and 2004 estimates for Area C and Area B&C combined. Only Area B had estimates among years which did not differ significantly.

Abundance had not been examined in the area between Tibbs and Central creeks (66 river km, Sections 1–14 of current study) since 1973 when 2,091 (SE=674) Arctic grayling ≥ 300 mm FL were estimated (Tack 1974). However, the 1973 abundance estimate is unreliable due to its high level of uncertainty, inability to ensure or test assumptions, and because the data collection methods were inadequate. The study design in 1973 specified that sampling be completed in as short of time as possible, which was 4 days with one crew (Tack 1974), whereas 3 crews required 14 sample days for the same area in 2012. Consequently, during 1973 only 258 ($n_1=136$, $n_2=122$, $m_2=7$) Arctic grayling ≥ 300 mm FL were captured compared to 1,534 ($n_1=697$, $n_2=837$, $m_2=120$) Arctic grayling ≥ 300 mm FL in 2012. Given the time it takes to float from Tibbs Creek to Central Creek, it seems very unlikely one crew could have representatively sampled all habitats encountered nor could have mixing occurred between events based on the 2012 movement data, thereby violating Assumption 2. Moreover, associated biases due to differences in capture probabilities relative to length or geographic strata could not be examined because of small sample sizes (i.e., $m_2 = 7$) and missing documentation of the data (i.e., capture locations).

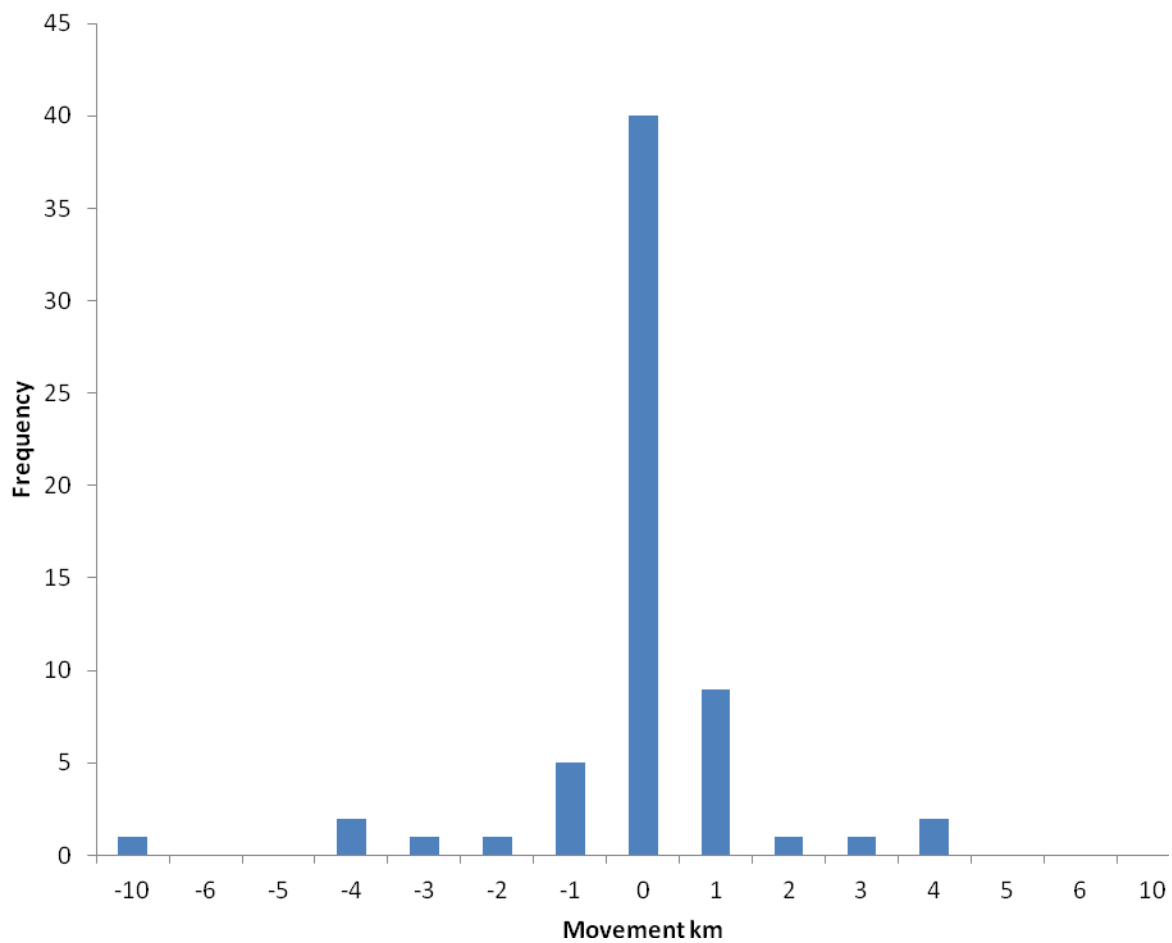


Figure 3.—Frequency of recaptured Arctic grayling (n = 159) that moved (km) upstream (positive values) or downstream (negative values) in the Upper Goodpaster River study area, 2012.

Table 2.—Results of diagnostics by size and Area used to detect and correct for size-selective sampling for estimating abundance and length compositions of Arctic grayling in the Goodpaster River, 2012.

Stratum	Comparison and Test Statistic			Result
	M vs. R	C vs. R	M vs. C	
≥240 mm FL Area C	D = 0.134 P-value = 0.142 Fail to reject H ₀	D = 0.129 P-value = 0.164 Fail to reject H ₀	D = 0.044 P-value = 0.661 Fail to reject H ₀	Case I
≥270 mm FL Area C	D = 0.113 P-value = 0.283 Fail to reject H ₀	D = 0.127 P-value = 0.167 Fail to reject H ₀	D = 0.046 P-value = 0.666 Fail to reject H ₀	Case I
≥300 mm FL (all)	D = 0.126 P-value = 0.037 Reject H ₀	D = 0.112 P-value = 0.075 Fail to reject H ₀	D = 0.038 P-value = 0.498 Fail to reject H ₀	Case II
≥300 mm FL Area A	D = 0.316 P-value < 0.001 Reject H ₀	D = 0.141 P-value = 0.288 Fail to reject H ₀	D = 0.195 P-value < 0.001 Reject H ₀	Case II
≥300 mm FL Area B	D = 0.158 P-value = 0.697 Fail to reject H ₀	D = 0.186 P-value = 0.478 Fail to reject H ₀	D = 0.106 P-value = 0.277 Fail to reject H ₀	Case I
≥300 mm FL Area C	D = 0.073 P-value = 0.863 Fail to reject H ₀	D = 0.126 P-value = 0.216 Fail to reject H ₀	D = 0.072 P-value = 0.238 Fail to reject H ₀	Case I
≥330 mm FL (all)	D = 0.138 P-value = 0.050 Fail to reject H ₀	D = 0.129 P-value = 0.076 Fail to reject H ₀	D = 0.047 P-value = 0.452 Fail to reject H ₀	Case I
≥330 mm FL Area A	D = 0.240 P-value = 0.012 Reject H ₀	D = 0.116 P-value = 0.603 Fail to reject H ₀	D = 0.163 P-value = 0.001 Reject H ₀	Case II
≥330 mm FL Area B	D = 0.118 P-value = 0.990 Fail to reject H ₀	D = 0.208 P-value = 0.559 Fail to reject H ₀	D = 0.123 P-value = 0.291 Fail to reject H ₀	Case I
≥330 mm FL Area C	D = 0.114 P-value = 0.580 Fail to reject H ₀	D = 0.175 P-value = 0.112 Fail to reject H ₀	D = 0.061 P-value = 0.657 Fail to reject H ₀	Case I

Table 3.—Results of consistency tests by size and Area for the Petersen estimator for estimating abundance of Arctic grayling in the Goodpaster River, 2012.

Stratum	Consistency Test		
	I	II	III
	Complete Mixing	Equal probability of Capture, 1 st Event	Equal Probability of Capture, 2 nd Event
≥240 mm FL Area C	$\chi^2 = 253.39$ P-value <0.01	$\chi^2 = 9.08$ P-value = 0.06	$\chi^2 = 3.76$ P-value = 0.44
≥270 mm FL Area C	$\chi^2 = 251.50$ P-value <0.01	$\chi^2 = 7.15$ P-value = 0.13	$\chi^2 = 5.52$ P-value = 0.24
≥300 mm FL (all)	$\chi^2 = 1484.58$ P-value <0.01	$\chi^2 = 29.89$ P-value = 0.01	$\chi^2 = 22.87$ P-value = 0.09
≥300 mm FL Area A	$\chi^2 = 161.56$ P-value <0.01	$\chi^2 = 15.47$ P-value = 0.01	$\chi^2 = 7.08$ P-value = 0.21
≥300 mm FL Area B	$\chi^2 = 58.29$ P-value <0.01	$\chi^2 = 7.88$ P-value = 0.10	$\chi^2 = 6.06$ P-value = 0.19
≥300 mm FL Area C	$\chi^2 = 227.82$ P-value <0.01	$\chi^2 = 6.17$ P-value = 0.19	$\chi^2 = 6.68$ P-value = 0.15
≥330 mm FL (all)	$\chi^2 = 1128.23$ P-value <0.01	$\chi^2 = 22.04$ P-value = 0.11	$\chi^2 = 14.02$ P-value = 0.52
≥330 mm FL Area A	$\chi^2 = 154.59$ P-value <0.01	$\chi^2 = 11.73$ P-value = 0.04	$\chi^2 = 4.24$ P-value = 0.52
≥330 mm FL Area B	$\chi^2 = 38.77$ P-value <0.01	$\chi^2 = 4.41$ P-value = 0.35	$\chi^2 = 5.00$ P-value = 0.29
≥330 mm FL Area C	$\chi^2 = 152.18$ P-value <0.01	$\chi^2 = 4.87$ P-value = 0.30	$\chi^2 = 3.18$ P-value = 0.53

Table 4.–Number of Arctic grayling ≥ 300 mm FL marked (n_1), examined (n_2), and recaptured (m_2) by section in the Goodpaster River study area, 2012.

		Section Recaptured																m_2	n_1	m_2/n_1^b
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16			
Section where marked	1	5	4															9	59	0.15
	2		16	2														18	95	0.19
	3			12														12	47	0.26
	4				4	1												5	46	0.11
	5				1	2												3	35	0.09
	6						3	2										5	31	0.16
	7							7										7	51	0.14
	8								3									3	31	0.10
	9									1								1	20	0.05
	10											1						1	14	0.07
	11											9	1					10	36	0.28
	12											1	15					16	72	0.22
	13												5	15				20	107	0.19
	14														10			10	53	0.19
	15														1	17		18	57	0.32
	16															2	6	8	61	0.13
m_2		5	20	14	5	3	3	9	3	1	0	11	21	15	11	19	6	146	815	0.18
n_2		50	76	122	23	36	49	72	16	32	8	49	112	79	113	95	53	985		
$(m_2/n_2)^a$		0.10	0.26	0.11	0.22	0.08	0.06	0.13	0.19	0.03	0.00	0.22	0.19	0.19	0.10	0.20	0.11	0.15		

^a Probability of capture during first event.

^b Probability of capture during second event.

Table 5.—Estimated abundance (\hat{N}_k), SE, and 95% CI by size and Area(s) for the population of Arctic grayling in the Upper Goodpaster River, 2012.

Stratum	\hat{N}_k	SE	95% CI	
			Lower	Upper
≥240 mm FL Area C	3,342	336	2,683	4,000
≥270 mm FL Area C	2,878	297	2,296	3,460
≥300 mm FL (all)	5,467	415	4,654	6,279
≥300 mm FL Area A	2,191	281	1,640	2,742
≥300 mm FL Area B	1,230	240	759	1,700
≥300 mm FL Area C	2,202	236	1,739	2,665
≥330 mm FL (all)	3,746	324	3,112	4,381
≥330 mm FL Area A	1,548	208	1,140	1,956
≥330 mm FL Area B	832	188	463	1,200
≥330 mm FL Area C	1,446	187	1,080	1,812

Table 6.—Number of fish sampled (n), sample proportion (p) and SE[p], and estimated abundance (\hat{N}_k) and $\hat{SE}[\hat{N}_k]$ by length category for the population of Arctic grayling (≥300 mm FL) in sample Area A of the Upper Goodpaster River, 2012.

Length					
(mm FL)	n	p	SE[p]	\hat{N}_k	$\hat{SE}[\hat{N}_k]$
300–309	16	0.05	0.01	112	31
310–319	29	0.09	0.02	203	44
320–329	33	0.11	0.02	231	48
330–339	40	0.13	0.02	280	55
340–349	31	0.10	0.02	217	46
350–359	35	0.11	0.02	245	50
360–369	36	0.12	0.02	252	51
370–379	27	0.09	0.02	189	42
380–389	21	0.07	0.01	147	36
390–399	19	0.06	0.01	133	34
400–409	9	0.03	0.01	63	22
410–419	8	0.03	0.01	56	21
420–429	5	0.02	0.01	35	16
430–439	1	<0.01	<0.01	7	7
440–449	2	0.01	<0.01	14	10
450–459	1	<0.01	<0.01	7	7

Table 7.—Number of fish sampled (n), sample proportion (p) and SE[p], and estimated abundance (\hat{N}_k) and $\hat{SE}[\hat{N}_k]$ by length category for the population of Arctic grayling (≥ 300 mm FL) in sample Area B of the Upper Goodpastor River, 2012.

Length (mm FL)	n	p	SE[p]	\hat{N}_k	$\hat{SE}[\hat{N}_k]$
300–309	30	0.09	0.02	112	29
310–319	39	0.12	0.02	146	36
320–329	30	0.09	0.02	112	29
330–339	38	0.12	0.02	142	35
340–349	38	0.12	0.02	142	35
350–359	36	0.11	0.02	135	34
360–369	39	0.12	0.02	146	36
370–379	20	0.06	0.01	75	22
380–389	30	0.09	0.02	112	29
390–399	12	0.04	0.01	45	15
400–409	11	0.03	0.01	41	14
410–419	4	0.01	0.01	15	8
420–429	2	0.01	<0.01	7	5

Table 8.—Number of fish sampled (n), sample proportion (p) and SE[p], and estimated abundance (\hat{N}_k) and $\hat{SE}[\hat{N}_k]$ by length category for the population of Arctic grayling (≥ 300 mm FL) in sample Area C of the Upper Goodpastor River, 2012.

Length (mm FL)	n	p	SE[p]	\hat{N}_k	$\hat{SE}[\hat{N}_k]$
300–309	86	0.11	0.01	236	35
310–319	75	0.09	0.01	206	32
320–329	107	0.13	0.01	294	41
330–339	95	0.12	0.01	261	38
340–349	120	0.15	0.01	329	45
350–359	113	0.14	0.01	310	43
360–369	66	0.08	0.01	181	29
370–379	67	0.08	0.01	184	29
380–389	35	0.04	0.01	96	19
390–399	18	0.02	0.01	49	13
400–409	12	0.01	<0.01	33	10
410–419	7	0.01	<0.01	19	7
420–429	1	<0.01	<0.01	3	3

Table 9.—Number of fish sampled (n), sample proportion (p) and SE[p], and estimated abundance (\hat{N}_k) and $\hat{SE}[\hat{N}_k]$ by length category for the population of Arctic grayling (≥ 300 mm FL) in 75 km of the Upper Goodpaster River, July 2012.

Length (mm FL)	n	p	SE[p]	\hat{N}_k	$\hat{SE}[\hat{N}_k]$
300–309	69	0.08	0.01	463	64
310–319	70	0.09	0.01	470	64
320–329	90	0.11	0.01	604	75
330–339	98	0.12	0.01	657	80
340–349	104	0.13	0.01	698	83
350–359	94	0.12	0.01	631	78
360–369	83	0.10	0.01	557	72
370–379	73	0.09	0.01	490	66
380–389	54	0.07	0.01	362	55
390–399	34	0.04	0.01	228	42
400–409	22	0.03	0.01	148	33
410–419	14	0.02	0.01	94	26
420–429	6	0.01	0.01	40	17
430–439	1	<0.01	0.01	7	7
440–449	2	<0.01	0.01	13	10
450–459	1	<0.01	0.01	7	7

Table 10.—Estimated abundance (\hat{N}_k), SE, and 95% CI by year and Area in the Upper Goodpaster River, and results of hypothesis tests to detect if 2012 estimates of abundance were not less than those of 2003 and 2004 ($\alpha = 0.05$).

Area B						
Year	\hat{N}_k	SE	95% CI		z-score	P-value
			Lower	Upper		
2003	1,182	154	880	1484	0.168	0.433
2004	851	133	590	1,112	1.381	0.084
2012	1,230	240	760	1,700		
Area C						
	\hat{N}_k	SE	95% CI		z	P
			Lower	Upper		
2003	1,340	199	950	1,730	2.792	0.002
2004	1,548	138	1,278	1,818	2.392	0.008
2012	2,202	236	1,739	2,665		
Areas B and C						
	\hat{N}_k	SE	95% CI		z	P
			Lower	Upper		
2003	2,454	239	1,986	2,922	2.222	0.013
2004	2,377	184	2,016	2,738	2.622	0.004
2012	3,329	313	2,814	3,942		

In comparison to other nearby rivers, the density of Arctic grayling ≥ 300 mm FL was relatively high in the Goodpaster River (75 fish/km). The Upper Chatanika and Chena rivers, which also share headwater areas in the unproductive (in terms of alkalinity) Tanana uplands and have similar hydrology (LaPerriere 1983), had densities of Arctic grayling ≥ 300 mm FL of only 31/km (80 km section of Chatanika River; Wuttig and Gryska 2011) and 36 fish/km (20 km section of Chena River; Wuttig 2004). In the adjacent White Mountains, Arctic grayling (≥ 300 mm FL) densities in Upper Beaver Creek were more similar at 65/km (49 km section; Fleming and McSweeney 2001). For perspective, the most productive waters in the Tanana River drainage have produced very high densities of Arctic grayling ≥ 300 mm FL in the Delta Clearwater River (636/km; Wuttig and Gryska 2010) and the Delta River (793/km; Gryska 2011b); however, these are two extraordinary cases.

The length composition of the 2012 population was quite different from that during 2003 and 2004, and it is the abundance of each size group rather than proportions that better illustrates the difference (Figure 4). While the abundances of Arctic grayling 360–459 mm FL has remained remarkably similar among years, the abundance of Arctic grayling 300–359 mm FL during 2012 was substantially greater, and indicates recruitment has improved during the intervening period. It is likely that the fish 300–359 mm FL represent multiple age groups rather than one or two cohorts recruited from exceptional rearing years. As grayling grow to 300 mm FL, discrete age groups become undifferentiated by size because Arctic grayling will begin to mature and grow more slowly at around 5–6 years of age when they are 270–300 mm FL (Clark 1992; DeCicco and Brown 2006; Gettal et al. 1997; Neyme 2005).

Development in the Upper Goodpaster River valley has not had detrimental effects on the Arctic grayling population as measured by abundance and size composition. In fact, the Upper Goodpaster River has an abundant Arctic grayling population relative to the productivity of the river, and there was some evidence that the population abundance has significantly increased since 2003 and 2004. Abundance can vary over time due to numerous variables that influence recruitment and mortality and this study did not attempt to determine what variables may have influenced changes in abundance. However, it is possible that primary productivity has been increased due to fertilization by treated effluent released into the river from the mine. Evidence of the increase in primary productivity was readily apparent where the treated effluent is released as the substrate is immediately and dramatically coated with thick aquatic bryophytes and other vegetation for a several hundred meters, unlike other locations in the river. Fertilization of nutrient poor streams and lakes has been demonstrated to increase primary productivity (Benstead et al. 2005; Bowden et al. 1994; Finlay and Bowden 1994) and growth and abundance of organisms, including Arctic grayling, at higher trophic levels (Benstead et al. 2005; Deegan and Peterson 1992; Johnston et al. 1999). Conceivably, the Arctic grayling population may have been similarly affected as evidenced by increases in abundance, particularly among Arctic grayling 300–359 mm FL. Given that these fish did not exist or were much younger and smaller when the mine became operational in 2006, it is possible that an increase in primary productivity has benefitted this group of fish in conjunction with other biotic and abiotic factors (Slavik et al. 2004). Validating the correlation between enrichment of the river and increases in the population were beyond the scope of this study, but future assessments should consider a study design that could evaluate the possible relationship.

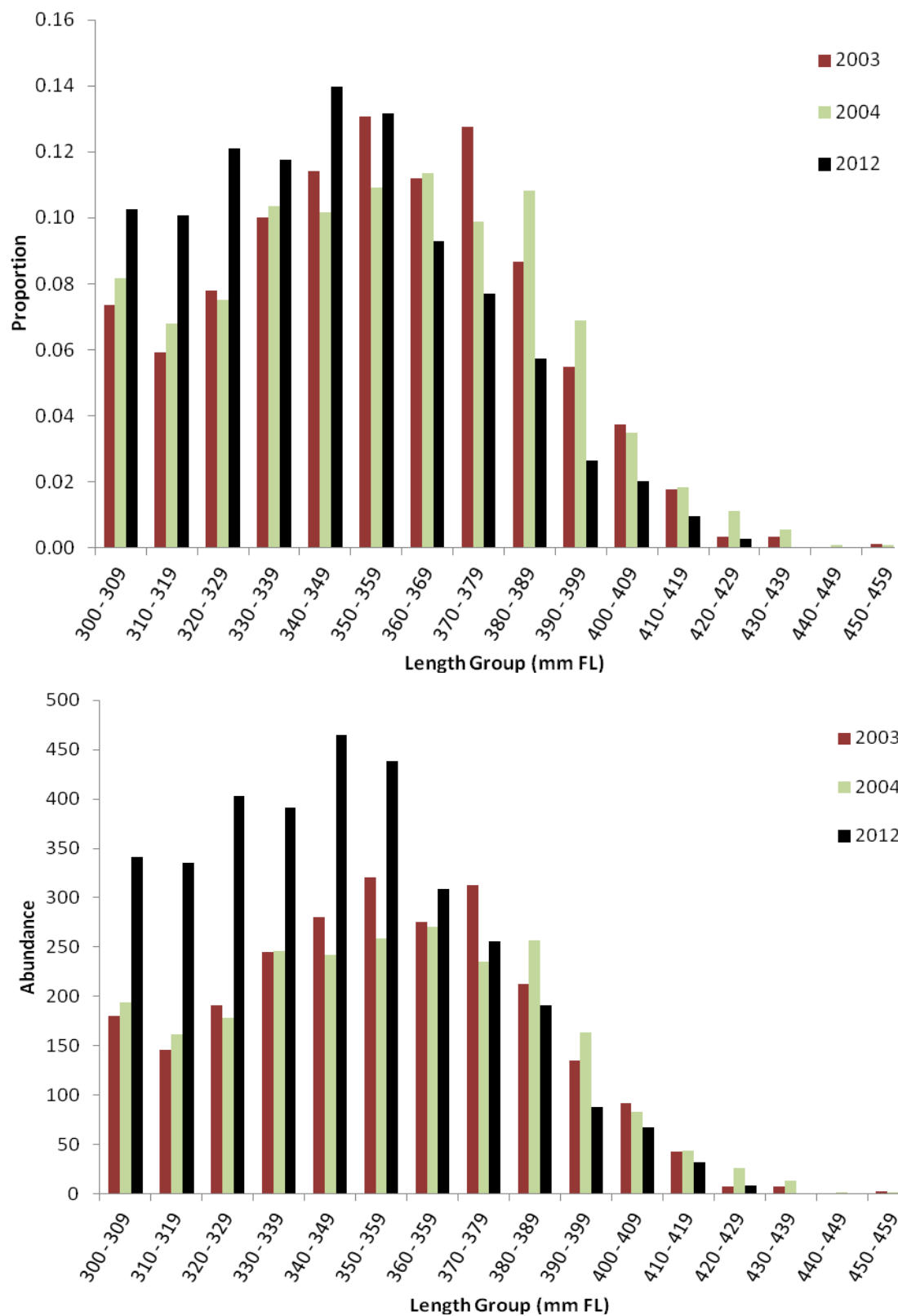


Figure 4.—Length compositions of Arctic grayling population ≥ 300 mm FL by proportion (upper panel) and by abundance (lower panel) for study Areas B and C during 2003, 2004, and 2012.

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APPENDIX A:
EQUATIONS AND STATISTICAL METHODOLOGY

Appendix A1.–Equations for calculating estimates of abundance and its variance using the Bailey-modified Petersen estimator.

The Bailey-modified Petersen estimator (Bailey 1951, 1952) was used because the sampling design called for a systematic downstream progression, fishing each pool and run and attempting to subject all fish to the same probability of capture while sampling with replacement. The Bailey modification to the Petersen estimator may be used even when the assumption of a random sample for the second sample is false when a systematic sample is provided:

- 1) there is uniform mixing of marked and unmarked fish; and,
- 2) all fish, whether marked or unmarked, have the same probability of capture (Seber 1982).

The abundance of Arctic grayling was estimated as:

$$\hat{N} = \frac{n_1(n_2 + 1)}{m_2 + 1}, \quad (\text{A1-1})$$

where:

n_1 = the number of Arctic grayling marked and released alive during the first event;

n_2 = the number of Arctic grayling examined for marks during the second event; and,

m_2 = the number of Arctic grayling marked in the first event that were recaptured during the second event;
and

The variance was estimated as (Seber 1982):

$$\hat{V}[\hat{N}] = \frac{n_1^2(n_2 + 1)(n_2 - m_2)}{(m_2 + 1)^2(m_2 + 2)}. \quad (\text{A1-2})$$

Appendix A2.—Detection of size and/or sex selective sampling during a two-sample mark recapture experiment and its effects on estimation of population size and population composition.

Size selective sampling: The Kolmogorov-Smirnov two sample test (Conover 1980) is used to detect significant evidence that size selective sampling occurred during the first and/or second sampling events. The second sampling event is evaluated by comparing the length frequency distribution of all fish marked during the first event (M) with that of marked fish recaptured during the second event (R) by using the null test hypothesis of no difference. The first sampling event is evaluated by comparing the length frequency distribution of all fish inspected for marks during the second event (C) with that of R. A third test that compares M and C is then conducted and used to evaluate the results of the first two tests when sample sizes are small. Guidelines for small sample sizes are <30 for R and <100 for M or C.

Sex selective sampling: Contingency table analysis (Chi²-test) is generally used to detect significant evidence that sex selective sampling occurred during the first and/or second sampling events. The counts of observed males to females are compared between M&R, C&R, and M&C using the null hypothesis that the probability that a sampled fish is male or female is independent of sample. If the proportions by gender are estimated for a sample (usually C), rather than observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are then compared between samples using a two sample test (e.g. Student's t-test).

M vs. R

C vs. R

M vs. C

Case I:

Fail to reject H₀

Fail to reject H₀

Fail to reject H₀

There is no size/sex selectivity detected during either sampling event.

Case II:

Reject H₀

Fail to reject H₀

Reject H₀

There is no size/sex selectivity detected during the first event but there is during the second event sampling.

Case III:

Fail to reject H₀

Reject H₀

Reject H₀

There is no size/sex selectivity detected during the second event but there is during the first event sampling.

Case IV:

Reject H₀

Reject H₀

Either result possible

There is size/sex selectivity detected during both the first and second sampling events.

Evaluation Required:

Fail to reject H₀

Fail to reject H₀

Reject H₀

Sample sizes and powers of tests must be considered:

A. If sample sizes for M vs. R and C vs. R tests are not small and sample sizes for M vs. C test are very large, the M vs. C test is likely detecting small differences which have little potential to result in bias during estimation. *Case I* is appropriate.

B. If a) sample sizes for M vs. R are small, b) the M vs. R p-value is not large (~0.20 or less), and c) the C vs. R sample sizes are not small and/or the C vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the second event which the M vs. R test was not powerful enough to detect. *Case I* may be considered but *Case II* is the recommended, conservative interpretation.

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C. If a) sample sizes for C vs. R are small, b) the C vs. R p-value is not large (~0.20 or less), and c) the M vs. R sample sizes are not small and/or the M vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the first event which the C vs. R test was not powerful enough to detect. *Case I* may be considered but *Case III* is the recommended, conservative interpretation.

D. If a) sample sizes for C vs. R and M vs. R are both small, and b) both the C vs. R and M vs. R p-values are not large (~0.20 or less), the rejection of the null in the M vs. C test may be the result of size/sex selectivity during both events which the C vs. R and M vs. R tests were not powerful enough to detect. *Cases I, II, or III* may be considered but *Case IV* is the recommended, conservative interpretation.

Case I. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated after pooling length, sex, and age data from both sampling events.

Case II. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the first sampling event without stratification. If composition is estimated from second event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the M vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case III. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the second sampling event without stratification. If composition is estimated from first event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the C vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case IV. Data must be stratified to eliminate variability in capture probability within strata for at least one or both sampling events. Abundance is calculated using a Petersen-type model for each stratum, and estimates are summed across strata to estimate overall abundance. Composition parameters may be estimated within the strata as determined above, but only using data from sampling events where stratification has eliminated variability in capture probabilities within strata. If data from both sampling events are to be used, further stratification may be necessary to meet the condition of capture homogeneity within strata for both events. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance.

If stratification by sex or length is necessary prior to estimating composition parameters, then an overall composition parameters (p_k) is estimated by combining within stratum composition estimates using:

$$\hat{p}_k = \sum_{i=1}^j \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik}; \text{ and,} \quad (\text{A2-1})$$

$$\hat{V}[\hat{p}_k] \approx \frac{1}{\hat{N}_\Sigma^2} \sum_{i=1}^j \left(\hat{N}_i^2 \hat{V}[\hat{p}_{ik}] + (\hat{p}_{ik} - \hat{p}_k)^2 \hat{V}[\hat{N}_i] \right). \quad (\text{A2-2})$$

where:

- j = the number of sex/size strata;
- \hat{p}_{ik} = the estimated proportion of fish that were age or size k among fish in stratum i ;
- \hat{N}_i = the estimated abundance in stratum i ; and,
- \hat{N}_Σ = sum of the \hat{N}_i across strata.

TESTS OF CONSISTENCY FOR PETERSEN ESTIMATOR

Of the following conditions, at least one must be fulfilled to meet assumptions of a Petersen estimator:

1. Marked fish mix completely with unmarked fish between events;
2. Every fish has an equal probability of being captured and marked during event 1; or,
3. Every fish has an equal probability of being captured and examined during event 2.

To evaluate these three assumptions, the chi-square statistic will be used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted for assumptions of the Petersen model (Bailey 1951, 1952; Chapman 1951) to be valid. If all three tests are rejected, a geographically stratified estimator (Darroch 1961) should be used to estimate abundance.

I.-Test for complete mixing^a

Section Where Marked	Section Where Recaptured				Not Recaptured (n_1-m_2)
	A	B	...	F	
A					
B					
...					
F					

II.-Test for equal probability of capture during the first event^b

	Section Where Examined			
	A	B	...	F
Marked (m_2)				
Unmarked (n_2-m_2)				

III.-Test for equal probability of capture during the second event^c

	Section Where Marked			
	A	B	...	F
Recaptured (m_2)				
Not Recaptured (n_1-m_2)				

^a This tests the hypothesis that movement probabilities (θ) from section i ($i = 1, 2, \dots, s$) to section j ($j = 1, 2, \dots, t$) are the same among sections: $H_0: \theta_{ij} = \theta_j$.

^b This tests the hypothesis of homogeneity on the columns of the 2-by-t contingency table with respect to the marked to unmarked ratio among sections: $H_0: \sum_i a_i \theta_{ij} = k U_j$, where k = total marks released/total unmarked in the population, U_j = total unmarked fish in stratum j at the time of sampling, and a_i = number of marked fish released in stratum i .

^c This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities among sections: $H_0: \sum_j \theta_{ij} p_j = d$, where p_j is the probability of capturing a fish in section j during the second event, and d is a constant.

Appendix A4.–Equations for estimating length composition and their variances for the population.

For Case I-III scenarios (Appendix A2), the proportions of Arctic grayling within each age or length class k were estimated:

$$\hat{p}_k = \frac{n_k}{n} \quad (\text{A4-1})$$

where:

n_k = the number of Arctic grayling sampled within age or length class k and,

n = the total number of Arctic grayling sampled.

When calculating n and n_k the diagnostic test results were used to determine which fish were included (Appendix A2). For Case I, fish from both capture events are used.

The variance of each proportion was estimated as (from Cochran 1977):

$$\hat{V}[\hat{p}_k] = \frac{\hat{p}_k(1 - \hat{p}_k)}{n - 1}. \quad (\text{A4-2})$$

The abundance of Arctic grayling in each length or age category, k , in the population was then estimated:

$$\hat{N}_k = \hat{p}_k \hat{N}, \quad (\text{A4-3})$$

where:

\hat{N} = the estimated overall abundance (Appendix A1).

The variance for \hat{N}_k was then estimated using the formulation for the exact variance of the product of two independent random variables (Goodman 1960):

$$\hat{V}[\hat{N}_k] = \hat{V}[\hat{p}_k] \hat{N}^2 + \hat{V}[\hat{N}] \hat{p}_k^2 - \hat{V}[\hat{p}_k] \hat{V}[\hat{N}]. \quad (\text{A4-4})$$

For the Case IV scenario (Appendix A2), that requiring stratification by size or sex, the proportions of Arctic grayling within each age or length class k were estimated by first calculating:

$$\hat{p}_{jk} = \frac{n_{jk}}{n_j} \quad (\text{A4-5})$$

where:

n_j = the number sampled from size stratum j in the mark-recapture experiment;

n_{jk} = the number sampled from size stratum j that are in length or age category k ; and,

\hat{p}_{jk} = the estimated proportion of length or age category k fish in size stratum j .

When calculating n_j and n_{jk} the within stratum diagnostic test results were used to determine which fish were included in the analysis following the rules for n and n_k provided above.

The variance calculation for \hat{p}_{jk} is equation 2 substituting \hat{p}_{jk} for \hat{p}_k and n_j for n .

The estimated abundance of fish in length or age category k in the population is then:

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$$\hat{N}_k = \sum_{j=1}^s \hat{p}_{jk} \hat{N}_j \quad (\text{A4-6})$$

where:

\hat{N}_j = the estimated abundance in size stratum j ; and,

s = the number of size strata.

The variance for \hat{N}_k will be estimated using the formulation for the exact variance of the product of two independent random variables (Goodman 1960):

$$\hat{V}[\hat{N}_k] = \sum_{j=1}^s \left(\hat{V}[\hat{p}_{jk}] \hat{N}_j^2 + \hat{V}[\hat{N}_j] \hat{p}_{jk}^2 - \hat{V}[\hat{p}_{jk}] \hat{V}[\hat{N}_j] \right). \quad (\text{A4-7})$$

The estimated proportion of the population in length or age category k (\hat{p}_k) is then:

$$\hat{p}_k = \hat{N}_k / \hat{N} \quad (\text{A4-8})$$

where: $\hat{N} = \sum_{j=1}^s \hat{N}_j$.

Variance of the estimated proportion can be approximated with the delta method (Seber 1982):

$$\hat{V}[\hat{p}_k] \approx \sum_{j=1}^s \left\{ \left(\frac{\hat{N}_j}{\hat{N}} \right)^2 \hat{V}[\hat{p}_{jk}] \right\} + \frac{\sum_{j=1}^s \left\{ \hat{V}[\hat{N}_j] (\hat{p}_{jk} - \hat{p}_k)^2 \right\}}{\hat{N}^2}. \quad (\text{A4-9})$$

APPENDIX B: DATA FILE LISTING

Appendix B1.–Data files for stock assessment of Arctic grayling in the upper Goodpaster River, 2012.

File Name
Upper Goodpaster River Arctic grayling population estimate data files for archive-2012.xls

Note: Data files are archived at and are available from the Alaska Department of Fish and Game, Sport Fish Division, 1300 College Road, Fairbanks, Alaska 99701-1599.